DEPENDENCE OF THE CONCENTRATION OF A PASSIVE SUBSTANCE ON THE DURATION OF THE MEASUREMENT

FERDINAND HESEK

Institute of Meteorology and Climatology, Slovak Acad. Sci., Bratislava*)

Zusammenfassung: Der Artikel hatte zur Aufgabe den Einfluss von Veränderung Beobachtungs-Intervalls auf die Konzentration der passiven, von erhöhter und stetiger Punkttequelle ausgelassenen Substanz auszudrücken. Zu diesem Zwecke wurde ein Modell der sog. nichtstationären Rauchspur — einer durchschnittlichen Rauchspur im Messintervall T — konstruiert. Man setzt voraus, dass die Verteilung von Teilchen in der nichtstationären Rauchspur eine Gauss'sche ist mit der Dispersion $\sigma_y^2(t)$, $\sigma_z^2(t)$ in den Richtungen $y$, $z$. Für die Dispersion $\sigma_y^2(t)$ wurde die Beziehung (15) abgeleitet. Analoges gilt in der Richtung $z$. Wenn uns die Auslenkung der Achse der nichtstationären Rauchspur von der Achse der stationären Rauchspur, der Geraden $(t, 0, H)$, bekannt ist, so können wir die Konzentration $q_T(t, y, z)$ explizit ausdrücken.

1. INTRODUCTION

A smoke plume, ascending from an elevated continuous point source, can have various shapes depending on the state of atmospheric turbulence. If the atmosphere is stably stratified, the smoke plume (fanning) fans out as a result of the air flow in a regular, undeformed shape and descends to ground level at a large distance from the source. If the atmospheric stratification is labile, the smoke plume (looping) is characterized by large deformations of shape. The magnitude of these deformations is subject to the existence of large scale turbulent fluctuations of the wind. The values of the average concentration over a sufficiently small observation interval under these conditions are not representative enough, because the values of the individual samples of concentration at a given point will differ considerably.

In most of the present theories the dispersion of the smoke plume from a fixed stationary point source causes the greatest difficulties in expressing the effect of large scale turbulent fluctuations of the wind direction on the resultant concentration. Therefore, these theories only consider the effect of turbulent fluctuations of small dimensions. In order to exclude the effect of large scale turbulent fluctuation of the wind direction on the average concentration, it is necessary to give the sampling time an upper limit. In most theories 3 minutes are considered the values of the average concentration over a 3-minute interval at a given point vary over a wide range. This is the result of the effect of turbulent fluctuations of the wind speed on a larger scale. The paper presented treats the problem of the effect of turbulent fluctuations of the wind speed on a large scale as regards the average concentration and, thus, the dependence of the average concentration as the sampling time. How ever, it was found [1] that on the sampling time. In order to describe the average spatial variance of the distribution of the particles in interval $T$, emitted by a point source, the concept of a non-stationary smoke plume is introduced. The model of the non-stationary smoke plume is identical with Gifford's model of an instantaneous smoke plume [2], only instead of considering the instantaneous state, one considers the average state over period $T$. The assumption that the distribution of the particles in the discs of the non-stationary smoke plume is Gaussian, changes the problem of computing the average concentration in interval $T$ to computing the distribution of the particles over a limited observation interval.

*) Address: Dúbravská cesta 4, Bratislava - Patrónka.
2. NON-STATIONARY SMOKE PLUME

Let us investigate the emission of a passive substance from a continuous point source at an elevation of $H$ above groundlevel. The origin of the co-ordinate system $(t, y, z)$ is at ground level and the positive $t$-axis is identical in direction with the average wind speed $U$ and the $z$ axis passes through the source.

In order to express the average concentration in a finite time interval $T$ it is convenient to introduce the concept of a non-stationary smoke plume. During the sampling interval $T$ the instantaneous smoke plume oscillates irregularly around the average wind direction as a result of the turbulent fluctuations of the wind direction. By averaging the spatial distribution of the concentration over interval $T$, one obtains the average non-stationary smoke plume. Just like the instantaneous smoke plume [2], it represents a set of an infinite number of adjacent elementary discs, of negligible thickness, and the non-stationary smoke plume can be divided into an infinite set of non-stationary discs. The distribution of the particles in a non-stationary disc at a distance $t$ from the source, will represent a time averaged particle distribution (over a limited interval $T$) in the plane $t = \text{const}$. Let it be assumed that the particle distribution in a non-stationary disc can be expressed by the function $f_T(t, y - D_y t, z - H - D_z t)$. For the concentration $q_T(t, y, z)$, measured in interval $T$, under the assumption of an ideal smooth groundlevel surface, one may then consider

$$\frac{U}{Q} q_T(t, y, z) = f_T(t, y - D_y t, z - H - D_z t) +$$

$$+ f_T(t, y - D_y t, z + H + D_z t) -$$

$$= \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \left[ f(t, y - D_y, z - H - D_z) + f(t, y - D_y, z + H + D_z) \right] \cdot g(t, D_y - D_y t, D_z - D_z t) \, dD_y \, dD_z,$$

where $g(t, D_y - D_y t, D_z - D_z t)$ is a function of the distribution of the centres of the elementary discs in the observation interval $T$, relative to the centre of the non-stationary disc. Let it be assumed that the function $g(t, D_y - D_y t, D_z - D_z t)$ has a Gaussian form

$$g(t, D_y - D_y t, D_z - D_z t) =$$

$$= \frac{1}{2\pi \sqrt{[D^2_{yT,0}(t) D^2_{zT,0}(t)]}} \exp \left[- \frac{(D_y - D_y t)^2}{2D^2_{yT,0}(t)} - \frac{(D_z - D_z t)^2}{2D^2_{zT,0}(t)} \right],$$

*) Symbols used: $t_L [s]$ — Lagrange characteristic time scale of turbulent fluctuations; $H [m]$ — elevation of source above groundlevel; $U [ms^{-1}]$ — average wind speed, independent of height above ground level; $t [s]$ — diffusion time, $t = x/U$; $T [s]$ — time of sampling; $a$ — dimensionless constant; $v [ms^{-1}]$ — component of the turbulent wind speed fluctuation along the $y$-axis; $D_y, D_z [m]$ — components of the deviation of the centre of an elementary disc from the straight line $y = 0, z = H$; $D_{yT}, D_{zT} [m]$ — components of the deviation of the centre of a non-stationary disc from the straight line $y = 0, z = H$; $Q [gs^{-1}]$ — source efficiency; $n [s^{-1}]$, $L(t) [s]$ — frequency and time scale of turbulent fluctuations dispersing elementary discs as wholes at a distance $t$ from the source; $q_T [gm^{-3}]$ — average concentration in interval $T$. 